Fluid Mechanics

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Lecture - 45
A Few Unsteady Flow Phenomena in Practice Part –II

Good morning. I welcome you all to this session of fluid mechanics. In the last class, we were discussing about the moving pressure wave in a fluid for the water hammer problem, when the valve is suddenly stopped. And we were on the way to deduce the expression for pressure rise due to the fluid deceleration to rest and the expression for the velocity of the pressure wave.

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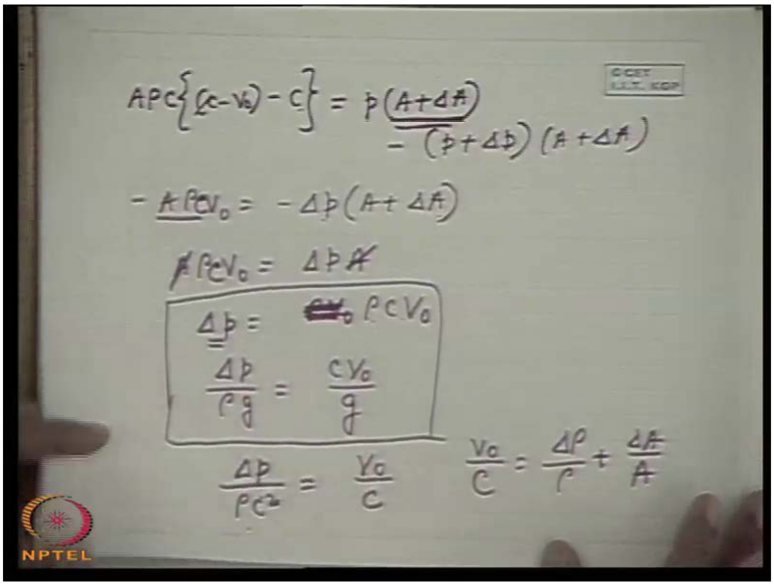

So, if you recall it, we see that, we deduce this expression for the pressure rise in the water, which all liquid for its coming to rest is this much delta p by rho g. It is the pressure rate, rise in pressure rate and we deduced up to this, that delta p by rho c square is delta p by E plus delta A by A, if you recall the earlier deductions.

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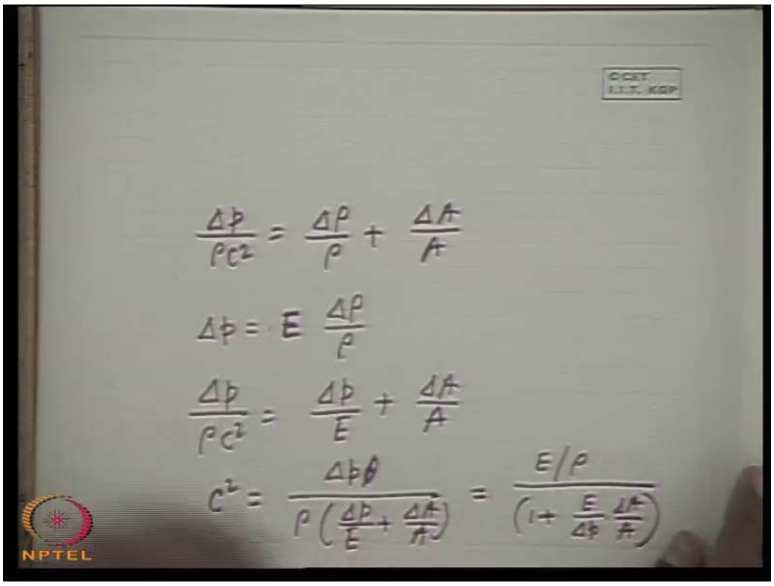

Then from here we can write, c square becomes equal to delta p by rho or at we can write delta p by rho into delta p by E plus delta A by A. And this can be written as delta p, if I take delta p by E as common, this can be written as E by rho into 1 plus E by delta p in to delta A by A. So, this is E by delta p delta A by A; now, here I like to replace delta A by A from such consideration.

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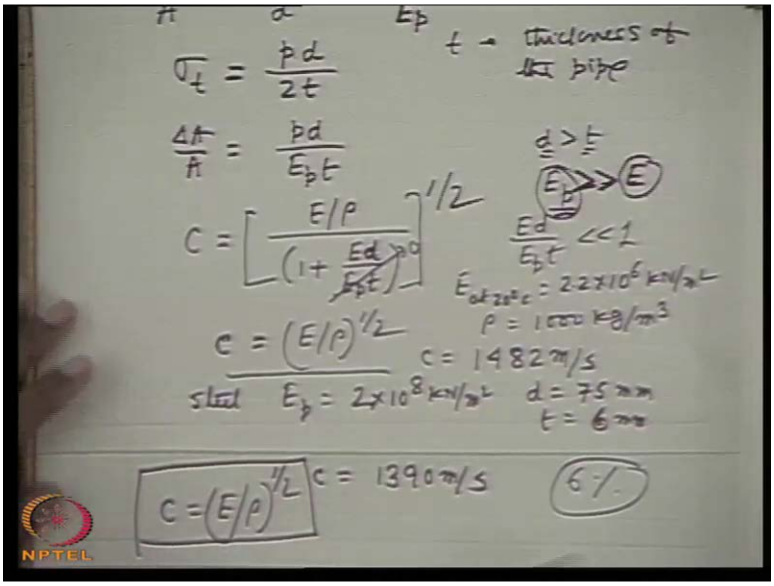

What is delta A by A? If we consider a circular pipe, where A is proportional to square of the diameter, delta A by A can be written as delta d that is change in it is diameter delta d. So, delta d by d in terms of the circumferential stress, if we consider this pressure rise in the fluid causes a circumferential stress and if E is the, E p is the modulus of elasticity for the pipe material, so this can be written as 2 sigma t by E p. So, therefore, delta a by a is so, delta t by 2, delta d by d is 2 sigma t by E p. So, therefore, if we now just substitute this 2 sigma t by E p. Now before that, I want to write that, sigma t the circumferential stress can be also expressed as, in terms of diameter p d by 2 t, this is also comes from the consideration of the strength of material; that means, the circumferential stress is related to the internal pressure, which causes this circumferential stress, diameter 2 t where t is the thickness of the pipe, thickness of the pipe, of the pipe. Now, if we substitute this sigma t there, then what we get? We get delta A by A is equal to, if you substitute this sigma t as p d by 2 t so, p d by E p into t.

Now, if this delta A by A is substituted in this expression of c square is equal to E by rho 1 plus E by delta p, delta A by A. We finally get an expression, C is equal to u k you get an expression E by rho divided by 1 plus E d by E p t. E is the modulus of elasticity for the liquid and E P is the modulus of the elasticity for the pipe; d and d is the diameter of the pipe; considering circular in cross section, t is the thickness of the pipe so, these whole to the power half.

Now, in all practical cases, we see that d is greater than t there is no doubt. Diameter of the pipe will be greater than it is thickness, but E p is much greater than E, it is by order of magnitudes (()) order of magnitudes more, that is the modulus of bulk elasticity or the modulus of elasticity. For the pipe material is two orders, more than that of the liquid. So, therefore, E d by E p t is usually much less than 1. So, we can neglect it. So that, C comes equal to E by rho for all practical purposes; E by rho to the power half, this is the expression for the wave velocity, C is equal to E by rho to the power half. So, we can give an example, what is the error of neglecting this? That if you consider water, whose E at 20 degrees Celsius is equal to 2.2 into 10 to the power 6 kilonewton, per meter square and rho is 1000 kilogram, per meter cube.

If you take this value and calculate it C from this, you get C is equal 1482 meter per second; now, if you consider the pipe material, then you will have to take for a particular pipe. If you consider steel as the pipe material, then E p for steel is some same, 2 into 10 to the power 8 kilonewton per meter square. So, if you take some typical values of d and t as some value d 75 millimeter; for example, and t is equal to 4 or 6, whatever you take

6 millimeter, you get this value of c as 1390 meter per second. If you consider by this formula, considering E t by E p t. So, therefore, the difference is almost 6 percent. So, you can neglect this. So, for all practical purposes, C is taken as E by rho whole to the power half. So, this is the expression of the wave velocity.

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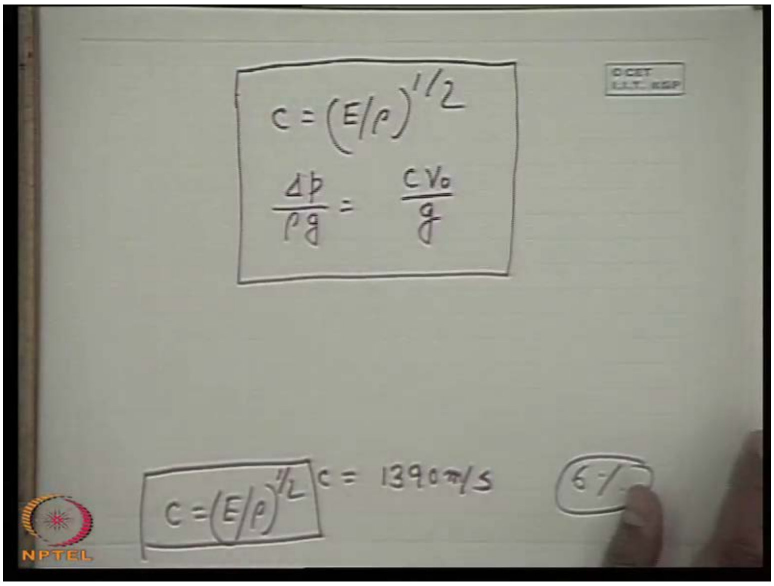

So, we get the wave velocity expression as, c is equal to E by rho whole to the power half and changes in pressure rate, delta p by rho g is c vg rho by g. So, these two expressions are very important from analytical point of view.

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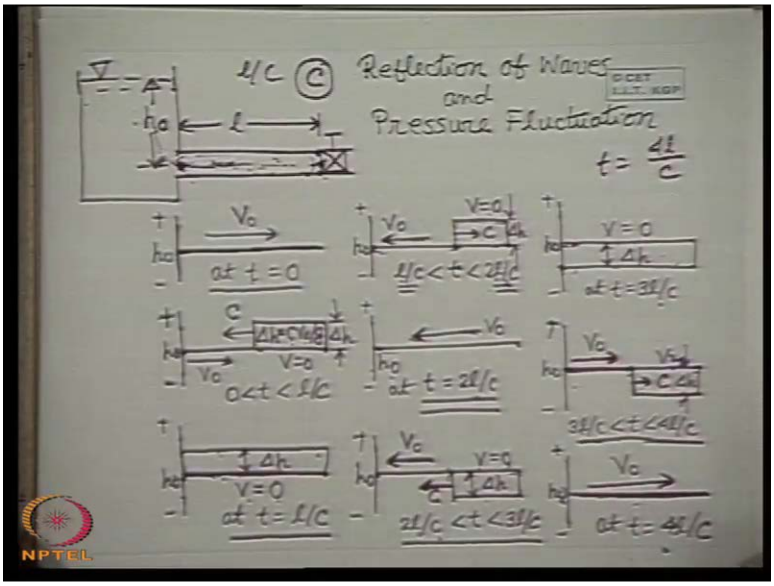

Now, we will come to very interesting phenomena. Now, that is when this pressure wave is generated in a column of fluid by suddenly decelerating the fluid; for example, stopping the valve, there is a pipe, there is a flow, flow is coming from a reservoir and the valve (()) stopped. So, that at the downstream location flow is decelerated to 0 and gradually the liquid column comes to rest by and pressure is increased by the propagation of a pressure wave, from downstream to upstream.

So, what happens? Because of the finite length of the tube so, these propagated pressure waves goes to upstream the reservoir and again comes back as a reflected wave to the downstream end of the valve and again as a reflected wave from the valve end, it goes back. So, there is a repeated to- and-fro movement of the pressure wave, which creates the problem, the pressure fluctuations and the knocking to the pipe line. So, this situation of pressure fluctuation is well depicted, how it is well depicted? We see now.

Let us see the situation the reflection of waves and pressure fluctuation; let us consider an inviscid fluid. So, this is the reservoir, let the head h 0 is maintained fixed, that is the initial head on the reservoir. When the pipe valve is closed this is initial (()) valve is open. So, then what happens? Initially the valve is not closed rather valve is open. So, we start the problem from the opening of the valve, it is under a steady flow velocity v 0 and this under head h 0 constantly. So, at t is equal to 0, this is the situation depicted that, this is the h 0 head, constant head at which the liquid is flowing at a constant velocity or at a steady state velocity v 0, when the valve is wide open.

Now, the instant when the valve is closed. So, a pressure wave is generated at the downstream end, that is the valve end and it is moving in with a velocity C, related to the fluid we know. So, we see at any instant 0 t is equal to 0 rather within t is equal to 0 to t is equal to l by c. Now, one thing we have to know that, when the velocity of propagation is C with relative to the fluid. So, therefore, the pressure wave takes time to reach the reservoir end a time l by c; during the time between 0 to l by c, the pressure wave will moves to some intermediate portion of the pipe.

So, this is the situation, where this portion the downstream portion, the pressure has increased to a value delta h; whose magnitude is c v 0 by g, which we have already deduced and this upstream part of the liquid is moving still with the velocity v 0 and it is head is h 0. The initial head or this head is more than the initial head by this amount delta h, this is the positive side; this is the negative side. So, at t is equal l by c, what will be the situation? Situation like that at t is equal l by c, the entire fluid in this pipe line is at 0 velocity and the head or the pressure in this pipe line is increase from the initial head h 0 by an amount h 0 plus delta h.

But this situation is an unstable situation, why? You see the liquid in the pipe reservoir is under head h 0 initial head. Whereas, the liquid in the pipe which is at a rest, but at a higher head than h 0, h 0 plus delta h. So, this causes the flow of the liquid to the reservoir; that means, the liquid will rushes into the reservoir. So, that the pressure in the liquid is equalized to h 0 pressure; this process of rushing the liquid at high pressure in the column to the reservoir to equalize the pressure again to the h 0 is conceived by movement of another pressure wave; which is in, which is conceived as the reflected pressure wave from the reservoir end to the downstream side. That means valve end and the action of this pressure wave, going from the reservoir in to the valve end is to super impose a negative delta h, a negative pressure is minus delta h, the negative pressure of delta h on this so, that ultimately the pressure rate is coming to h 0. So, this is the situation between a time intervals of l by c to 2 l by c because, it is from the initial again this pressure wave to reach there, it will take the time l by c. So, at a time, after a time 2 l by c only; this reflected pressure wave will reach there. So, that any time in between from l by c to 2 l by c, this situation is like that, that is the reflected negative pressure wave has reached here; which has super imposed this part of the fluid from where it has passed, that is the downstream compared to this moving pressure wave is the head is h 0 whereas, this part of the liquid is still at a higher end, delta h and velocity is 0.

That means, when the pressure wave has passed the reflected pressure wave or negative pressure wave from the reservoir, in to these bulk streaming. So, when we first do the fluid, it sets a velocity v 0 in this direction; because, physically the fluid is rushing in to the reservoir and it is a head is being restituted to its original value h 0. That means minus delta h pressure rate is super imposed on the fluid by this moving pressure wave. So, this is the situation between a time of l by c to 2 l by c. So, exactly at time t is equal to 2 l by c this pressure wave has reached here. This is the reflected pressure wave from the reservoir; it is the negative pressure wave, when it has reached here the entire fluid or liquid is at head h 0; that is the initial head, but it is moving in this direction v 0 towards the reservoir, but this situation is again non-stable. Why? When this v 0; that means, out of inertia. So, this liquid is still moving in this reservoir with a velocity v 0, when the entire fluid has reached a pressure h 0.

So, to maintain that inertia the liquid; that means, with a velocity v 0 in this direction, the liquids suffers the decompression; that means, the pressure in the liquid column decreases, this is being conceived by again the movement of a pressure wave, negative pressure wave from the valve end to the reservoir end. Means the action of this pressure wave is to super impose; again a negative pressure head, which is again the delta h magnitude is same c v 0 by g on the fluid element; that means, again a pressure wave will move after the time t to l by c, in towards the reservoir end. By super imposing a negative pressure rate in the fluid and again to make the fluid at rest; that means, this v 0 physically this velocity in this direction will be arrested, when there will be a negative pressure created in the liquid column in the pipe.

So, this is the situation for the time is 10 t between 2, 2 l b y c to 3 l by c when the negative pressure wave has moved up to this point or this section from the valve end where the velocity is set to 0 and the negative pressure rate of delta h is super imposed. This is the h 0 this is the h 0 whereas, in these part of the fluid it is still moving with v 0 velocity in this direction; that means, in the reservoir direction and the pressure wave is moving in this direction with respect to c.

So, therefore, we see at time t is equal to 3 l by c, this pressure wave will again reach the reservoir end. So, when this situation corresponds to a situation, when the entire liquid in the column is at a negative pressure from the original pressure, uniform by delta h negative pressure, that means the entire liquid column is at a negative pressure; whereas the reservoir fluid at h 0 pressures. So, again a fluid will come from the reservoir to this column; that means, again a positive pressure wave, then will travel from the reservoir end to the valve end; after a time t is equal to 3 l by c. Whose action will be to super impose, a plus delta h pressure rate on the fluid column. So, this is moving, a time of t between 3 l by c and 4 l by c will see the pressure wave is moving like that and in that case, the liquid is moving from the reservoir to the pipe. That means to set the fluid a velocity v 0 in this direction and again to counter wave this minus delta h from h 0. So, that from the fluid head is h 0 and this part is again at delta h and this is moving with c velocity, with this part is delta h and v is equal to 0. That means this situation, when this, when this is at this position. So, exactly at t is equal to 4 l by c, then the entire liquid column will be at h 0 head and with a velocity v 0 in this direction; which is same as that at t is equal to 0.

So, at t is equal to 2 l by c, the entire liquid is at h 0, but velocity is in the opposite direction to that of the initial direction; that means, towards the reservoir. So, only at t is equal to 4 l by c, we get the initial condition or initial situation to be restored. Then; that means, the entire liquid in this column or in this pipe is at a head h 0 and is velocity is v 0 towards the valve. Therefore, we see a cycle of events is completed; whose time period t is equal to 4 l by c and this time, this cycle of events will be repeated indefinitely, if the fluid inviscid with the amplitude, remaining undiminished; amplitude means this is the pressure rate remaining undiminished, this cycle of events will be repeated indefinitely. However in actual cases, because of the viscosity the amplitude gets diminished and ultimately it is dying out after few cycles, this is the reflection of waves and pressure fluctuations; now, let us find out that due to this reflection of waves to-and-fro.

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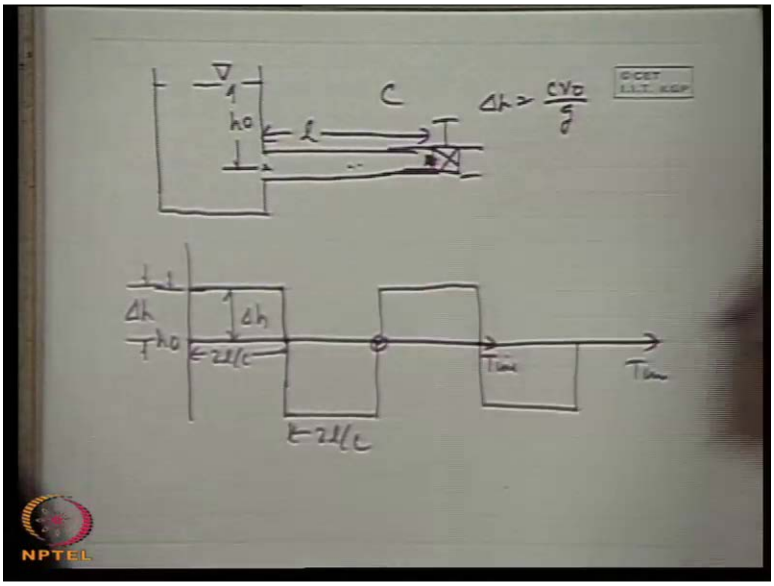

What is the situation of pressure fluctuation or pressure versus time, at some location in the pipe or at the valve end, let us consider. So, this is the valve let us consider that, this is the h 0; let us consider, what is the pressure fluctuation due to this thing, at the valve end or at any location. Let us consider the point at the valve end and if we try to find out what is the pressure fluctuation due to this movement of this pressure wave at valve end, that any point at the valve end here. So, at t is equal to 0, let this is the time at t is equal to 0; the immediately the pressure goes from h 0, that is h 0 to delta h; that means to delta h so, this is, this is delta h which is c v 0. We know that delta h c v 0 by h, this will move to a distance l with a velocity c. So, it will come here and then go again here, which will take, which will take 2 l by c times during, which the pressure rate will remain as 2 l by c pressure rate will remain as delta h.

So, up to a time of 2 l by c the pressure rate here will remain as h 0 plus delta h, h 0 is the initial head; then at 2 l by c what happens? A negative pressure will lead come this negative pressure wave will first diminish this delta h to h 0 and at the same instant, another negative pressure wave will starts as I have discussed earlier in this direction. So, the pressure wave at that instant t is equal to 2 l by c, will fall to a negative minus delta h; you see that? If you see, that is so on at 2 l by c, this is the situation just that 2 l by c this wave will come. So, here the negative pressure wave will fall therefore, this is 2 l by c and we see again, this will continue for a period of 2 l by c because, the negative pressure wave will go here again and again will come back as a positive pressure wave.

So, that it will come, it will take time l by c plus l by c, 2 l by c so, that again it comes to this situation, this cycle of events will go on repeating like this with time. So, this is the typical pressure fluctuation is taped type fluctuation, with time at a point on the valve end.

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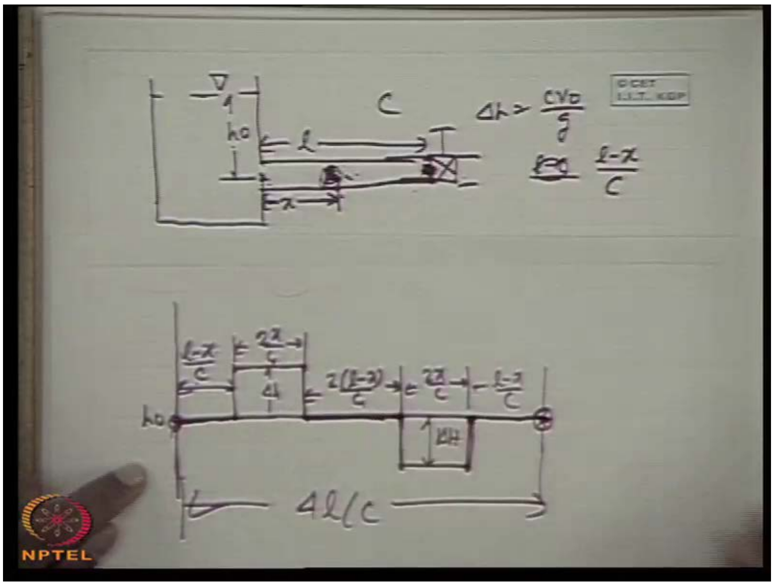

So, what will be that at a point, on the reservoir at any point at a distance x, from the reservoir end; what is that? At a point x from the reservoir end, if we consider this is most interesting, you see this is most interesting that, if this be the h 0; after the time t is equal to 0, the head is h 0 because, it will take some time to reach here, it will take some time to reach here. So, what is the time taking that wave pressure wave to reach here? It is l minus c by l minus x by c l is this length of the tube, this distance is x. So, therefore, l (()). So, after a time l minus x by c the pressure rate will go on increasing to delta h; this is l minus x by c. So, pressure rate will increase to delta h now, this will rest up to a time. So, this pressure rate will remain delta h above h 0 will remains. So long this pressure wave goes here and comes back as a reflected pressure wave, which will take a time x and x, 2 x by c. So, during a period of 2 x by c, this pressure wave will be delta h; after that what will happen? The pressure wave will super impose the negative pressure wave and it will fall at 0. So, it will remain 0; So long this pressure wave goes here understand and again another negative pressure wave comes here, which will take a time of 2 into l minus, this is l minus x by c.

So, for a period of 2 into l minus x by c; that means, this period; let us write this 2 into l minus x by c up to this period. So, it will be at a head h 0, after which it will be again at a negative head; that means, this negative pressure wave will reach here. So, this will be again, this negative head, this will be creating a negative head in the pressure wave, negative pressure will pass through this and it will remain to that delta h to a up to a time period, that this negative pressure wave goes here and comes back again from here; as a positive pressure wave that time is again 2 x by c. So, again it comes to the positive pressure, this pressure wave when it passes through here it makes the pressure head h 0 and it will take a time l minus x by c, when this pressure wave reaches here. So, this time also is c. So, this is l minus x by c, this point will correspond to this point from here again after l minus x by c, this cycle will start; that means, this point corresponds to this point. So, if we add up all this time l minus x by c, 2 x by c this. So, the time period of this cycle is 4 l by c.

But the pressure fluctuation is like that from t is equal to 0 up to a time l minus x by c where c is the wave velocity pressure wave velocity related to liquid then there will be h 0 head initial head at any point x from the reservoir (()), then immediately the pressure will increase to delta h and it will remain to a value of h 0 plus delta h over a time interval 2 x by c where x is the distance from the reservoir end then the pressure will again fall up to a after a time of l minus x by c plus 2 x by c this time interval and then it will remain at h 0 for a time interval of 2 l minus x by c.

Which is the time taken for the pressure wave to go the valve end and again coming back to this point again, if the pressure will decrease; that means, the pressure wave will be h 0 minus delta h for a time interval of 2 x by c and at this instant given by this time from initial time, this will be again coming to the initial h 0, initial pressure rate and this is the point corresponding to the this point in the pressure wave has reached, that is the positive pressure wave has again reached to this valve end. So, this is the typical pressure fluctuation at any point x in the pipe line due to this repeated movement of pressure waves.

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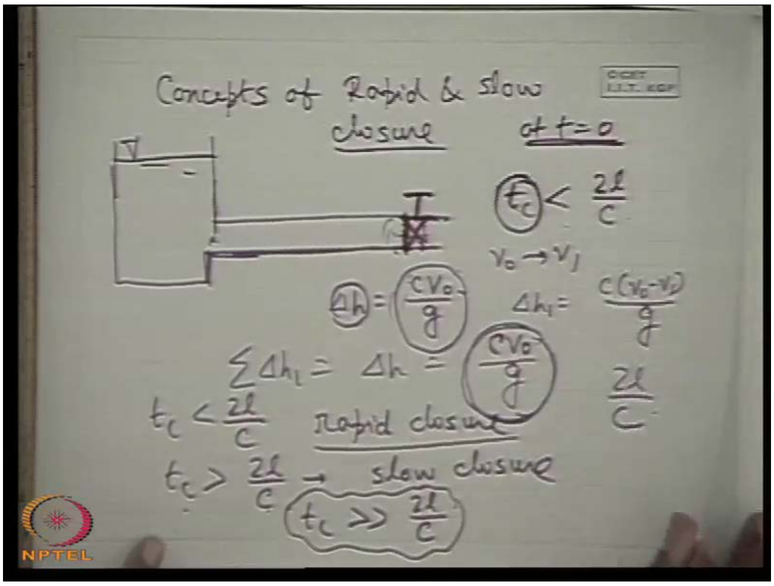

Now we will come to the concepts of rapid and slow closure; we will come to the concepts of rapid and slow closure. What is meant by rapid (())? Let us consider again, a pipe line with the valve under some head of some liquid. So, this is suddenly closed, what is meant by rapid and slow closure? Now, in practice no valve can be closed instantaneously. So for, we have considered the valve is closed instantaneously; that means, at t is equal to 0, we start telling that the decompression of the fluid adjusting to the valve has taken place; that means, the pressure wave has start moving from the valve end, just at t is equal to 0. Which means we consider at t is equal to 0, the valve is completely closed, but the complete closure at the t is equal to 0 is impossible; there is always some finite time taken for the valve to close now, if this time is taken as t c, then we see that one very interesting thing that, So long t c is less than 2 l by c; the pressure head generated at the valve end will not be changed from the previous quantity; that means, we know that pressure rate generated due to the total deceleration of the fluid is c V 0 by g.

Now, if the valve is not closed, immediately this is the instantaneous closure valve is closed during a time of t c. So, what happens, during some time less than t c. So, valve will be partially closed, what the velocity of the fluid is decelerated from V 0 to some other velocity V 1; for example, V 0 to V1. So, the pressure rate developed will be less than this, in that case the pressure rate developed; in that case delta h 1 is C V 0 minus V 1 by g. So, what happens the pressure rate will gradually developed to C V 0 by g, when the valve will be fully closed.

Now, if this closure of the valve takes a time less than 2 l by c; then what happens, before a negative pressure wave reflected negative pressure wave comes here; for example, the pressure wave which was generated at the beginning? The first pressure wave due to the first closure of the valve is the very first pressure wave, which is generated for the decelerating of the liquid; we will take time 2 l by c to travel to the reservoir in and come back before any reflected wave, come before any reflected wave comes to the valve end; the entire pressure will be developed because, the valve will be completely closed and that entire pressure wave will be developed; that means, sigma of all these delta h 1 will be delta h.

So, before any reflected wave comes to the valve end, the pressure development is the same as that for an instantaneous valve closure. So, this case is known as the rapid closure. When t c is less than 2 l by c we call this as a rapid closure, which gives the same pressure rate develop at the valve end, as that of the, as that in case of instantaneous closure and the physical situation is sent, Now we consider the case, when t c is greater than 2 l by c, what happens? That means, before the valve is completely closed and fluid is completely brought to rest a reflected wave will arrive here. Because, the first pressure wave will generated will go to the reservoir end and come to this valve end by a time of 2 l by c from the beginning, t is equal to 0. So, if the time of closure is more than 2 l by c, before the valve is completely close, a reflected pressure wave will reach here. So, that it will not allow the liquid to act it is maximum head or rising head as it could have obtained by decelerating the flow of fluid instantaneously. So, this is known as slow closure and if the closure is still very slow; that means, much more than 2 l by c in that case the compressibility effect may be ignored; that means, this does not come into the consideration of a rapid change in the flow of velocity. So, that compressibility comes into consideration.

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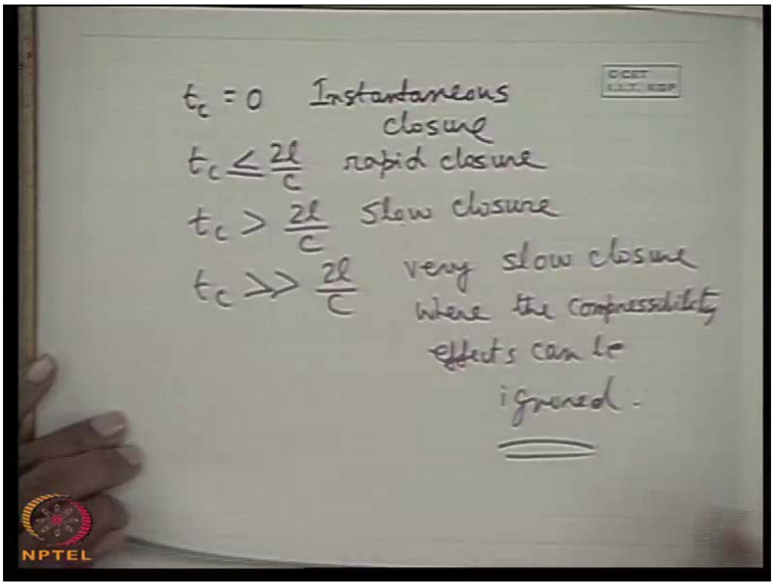

So, therefore, we can write that there are three types of closure, when go to 0 this is instantaneous, instantaneous closure, when t c is less than 2 l by c; this is known as rapid closure. Where the pressure rate develop will be the same as C V 0 by g as that of the instantaneous closure for the valve end and t c I am greater than 2 l by c, t c is less than equal to 2 l by c, rapid closure greater than 2 l by c is slow closure. Where the pressure rate developed, even at the valve end will be less than that develop for instantaneous closure or rapid closure or t c very greater than, very slow closure, very slow closure where the compressibility effect compressibility, compressibility effects can be ignored, can be ignored.

Now, most interesting fact is that even if there is a rapid closure t c is 2 less than 2 l by c, then in a pipe, the entire pipe does not reach the maximum pressure rate generated; only the valve end always reaches the maximum pressure rate generated.

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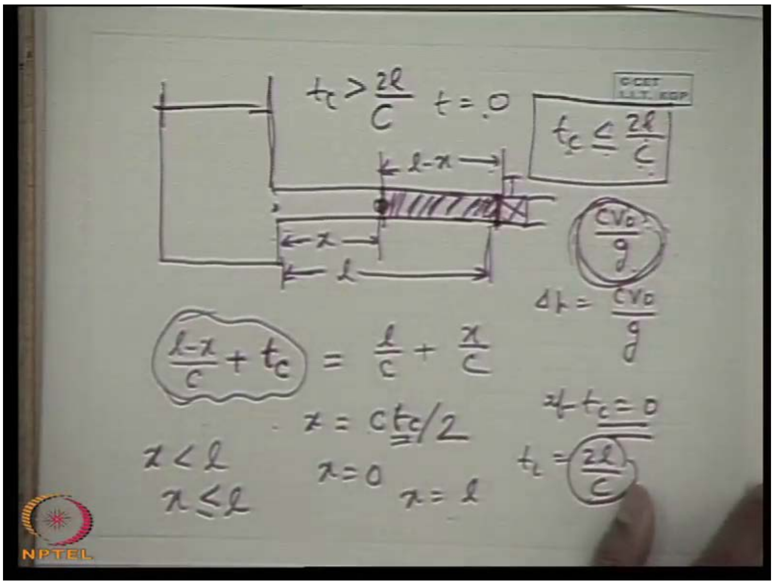

This is obvious, this is because, if the valve closure time t c is there, which is less than of course, 2 l by c then though the valve end the pressure rate developed is C V 0 by g ((]), this is not true for any other point. This is big because, the time taken for any other point to receive a negative pressure wave after the time, when a positive pressure wave has changed his head will be less than the point to suffer the maximum change in head. Well let us find out that, what up to what length the tube will be suffering the or the pipe will be suffering the maximum change in head; delta h is C V 0 by g, how to find out it? Let this from the reservoir end this point distance x. That means we specify the problem that, l minus x is the length from the valve, valve end; that means, this is l from the valve end, the l is the length. So, l minus x is the length which will be subjected to the maximum rise in pressure.

How to find this value of the maximum rise in pressure? This can be found out by the value by equating the time, which is taken by the wave, reflected wave to move from this position, going to the reservoir coming back with the time required for the pressure to be generated here. Now, you see the first wave will reach here at a time l minus x by c; first pressure rate then if, t c is the time of closure. So, we can tell from time t is equal to 0, this is the time taken for this part of the pipe to be raised to this maximum pressure rise because, l minus x by c is the time taken for the first wave to reach here, which will increase the pressure rate to some extent; then t c is the complete closure time. So, after that if we add l minus x by c, t c plus this so, after these time the entire pipe will be at the maximum pressure rate rise.

If this is equal to the reflected wave for the first pressure wave to come here; that means, first pressure wave was generated here at t is equal to 0. So, it has reached here at a time l by c from t is equal to 0, the first pressure wave reaches the, first pressure wave reaches here at l by c time, then comes here plus x by c. So, therefore, any reflected wave to appear at this point for the first time, this point has already changed or suffered the maximum rise in the pressure end. So, if you make an equation like that, we get l by c l by c.

We can say, we finally get x is equal to c t c by, 2 c t c by 2. So, l by c, l by c cancels; 2 x by c is equal to t c. So, x is equal to c t c by 2. So, depending upon the value of t c x will depend; that means, if t c is equal to 0 that is instantaneous closure x is equal to 0; that means the entire pipe will be subjected to the maximum pressure. Now you see t c is equal to 2 l by c, you write t c is equal to 2 l by c; what is the x 2 l by c? That is l; that means, it will be only at the valve end; that means, at the extreme time; that means, t c is less than equal to 2 l by c, for a rapid closure. That means, when t c is equal to 2 l by c, then the maximum pressure rise will take only at the valve end, but t c is less than 2 l by c; if you see x will be, x is not x will be less than l, if you put t c is less than 2 l by c; we get x is equal to l. That means x is less than equal to l depending upon t c less than equal to 2 l by c. So, t c is greater than 2 l by c, we see c that x; that means, none of these; that means, x will be greater than l; that means, the none of these pipe that means, not even in the valve end the pressure the maximum pressure rise will be occurring. So, this is the concept of rapid closure and slow closure. Now, I will come that way think that, how you can find out for a slow closure the change in the pressure rate at the valve end?

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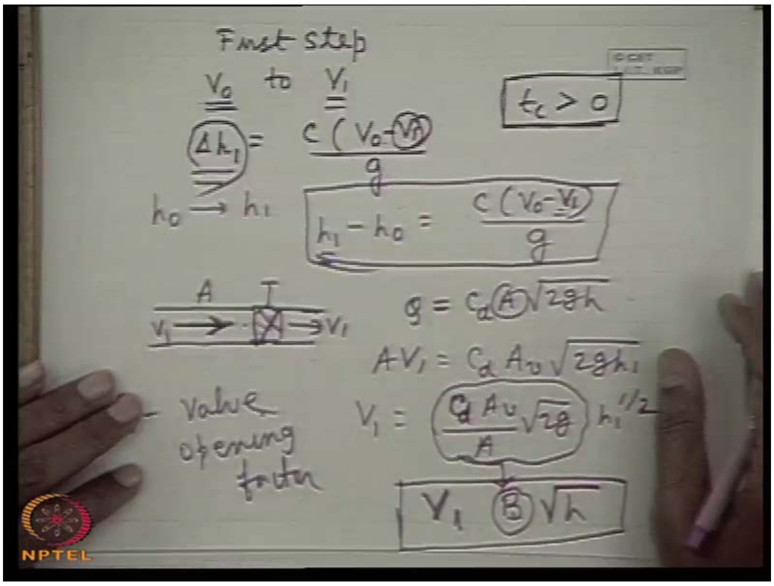

How we can find out the problem is like that, if we consider for a slow closure the velocity is changing from V 0 to V for example, V 0 to V 1; then we can write the delta h that is the pressure rate rise is for the slow closure is delta h 1 for the first step. Now, before that we consider we must tell I have forgotten to tell you that, this slow closure problem; that means, t c slow or rapid closure problem, that t c either less than equal to 2 l by c or rather I write here t c; that means, any value of t c greater than 0, which is either rapid closure or slow closure; the problem is thought in this way that, the valve closing is considered in discrete states, if valve closing is considered in discrete case, which is continuous in practical situation considered to be in discrete steps of time; which are multiples of sub multiples of 2 l by c and we consider that, the valve, the entire valve closing which is actually a continuous operation in practice to be in steps of interval of 2 l by c or sub interval of 2 l by c and in each discrete steps it sends a pressure wave, which resists the pressure of the fluid and decreases it is velocity and during that time; the valve remains stationary after which, after the entire fluid is being pressurized and decelerated; then another step of valve closing takes place. So, with this an idea, if we consider that the first step of bulk closing, the first step, the first step of bulk closure. So, liquid velocity is changing from V 0 to V 1, delta h 1is C V 0 minus V 1 by g, not C V 0 minus 0 by g.

This will also can be found out by writing the momentum equations, this you can find out by writing the momentum equations through the pipe. So, that we can get delta h 1 is equal to C V 0 minus V 1 by g; now, if the initial head is h 0 and final head is h 1 then, we can write h 1 delta h 1 as h 1 minus h 0 as C V 0 minus V 1 by g.

This is the pressure head rise because of the deceleration from V 0 to V 1; now, here there are two unknowns h 1 and V 1 to be found out, we do not know up to what velocity the liquid has been decelerated? So, to do this, we require to find this h 1 and V 1 simultaneously, we require another equation. To get another equation, we consider the valve opening like this, that this is the valve; valve opening through which the fluid is being discharged with a velocity of V 1, but the fluid is coming approaching this with a velocity V 1. So, this is the V 1 with a velocity V 1 as an orifice. That means the partial closure of the valve will act as an orifice; how an orifice? We know Q with an orifice, whose Q is given by C d, the coefficient of discharge is working like an orifice; what is the orifice equation for the rate of discharge? C d into area of the orifice into root over 2 g h.

So, here Q is can be retained as area of the pipe A into V 1, that is same which is coming from here; even if the area is, area opening of the thing is different, that is C d into area of the orifice, that is the area of the valve, that is the valve opening after the first step the valve is partially closed and the root over 2 g h. So, we can write V 1 is C d, A v by A into h 1 to the power half. So, this is a constant, usually though the coefficient of discharge for this valve opening varies with the velocity, but we can take this as V as a constant and known as valve opening factor.

So, therefore, we see valve opening factor; therefore, we see, we have two equations if we know the value of the valve opening factor V 1 sorry B. So, we get V 1 is some constant u, which is the valve opening factor comprises this C d, A v root over 2 g times root over h and another is this simultaneous solutions of these two equations, give the value of h 1 V 1; that means, we can find out, what is the pressure rise in the first stage and the corresponding decelerated velocity after the first stage, these way each steps are calculated in the this process.

Now at the end I will tell you the most important thing in practice, because of the these water NMR problems for the implication of such tank; now, in a hydroelectric power station as we know, when the liquid is fed from a high head spin storm turbine then what happens, when the turbine load changes the flow of water has to be altered. So, these causes sudden acceleration and deceleration in the long penstock, long penstock leading to the turbine, which faces severe water NMR problems; for example, when load is increased, water flow has to be increased; when the load is decreased sudden deceleration of the water has to take place for which the pipe line, that is the penstock suffer the water NMR problem.

To reduce that problem the surge tank is used, that is nothing, but an open tank which is placed very close to the turbine in the attaché to the penstock. So, that a long portion of the penstock, that is the pipe leading the turbine from the large overhead reservoir suffers a large portion of that does not suffer the water NMR problem; whereas, the small portion from the surge tank to the turbine, suffers the water NMR problem.

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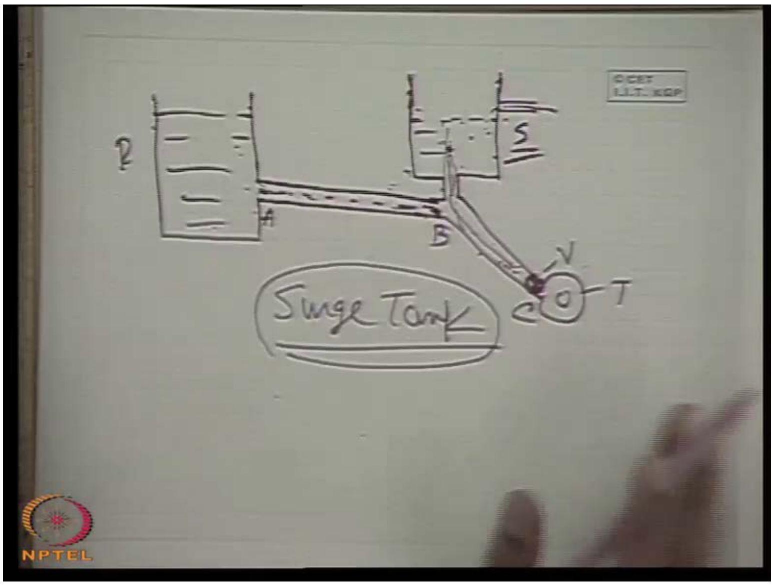

Let us very quickly see this thing, let us consider this is this; now, you see that this is the pipe line. So, this is the tank, well this is the tank inlet and this is the turbine, right this is the turbine, this is the valve, this is the valve V. So, this is the reservoir R from where the water is coming to the penstock. So, this part of the penstock is laid at a less, lesser slope, and this is the surge tank whose height, whose top is more higher than this. So, this is the water (()). What happens, when the load is reduced? This valve is suddenly close, surplus water goes to the surge tank. So, that the head in the surge tank goes on increasing, which gives a decrease in the head causing flow between reservoir and surge tank. So, the water flow in this long part of this penstock, this pipe line A to B is gradually decreased and does not face this water NMR problem whereas, B to C only the lesser part of this penstock suffers the water NMR problem; for which the surge tank is placed very near to the turbine and another thing, when the flow is increased, when the load is increase suddenly the flow is increased. What happen? This surplus flow comes from this surge tank to this pipe. So, that this pipe does not face a sudden acceleration of the flow.

So, therefore, by providing this surge tank, we can avoid the water-hammer problem; when the deceleration is very sudden, that some more water has to go to the surge tank, the surplus water here to reduce this flow in this pipe gradually, the over flow line is there. So, that water can overflow from this surge tank; therefore, from these application of this surge tank, surge tank we can tell that surge tank is reduces the water NMR problem in the greater part of the penstock; when the flow is reduced due to the reduction in the load and at the same time it meets up the surplus water when the load is increase and also it takes the surplus water, when the load is decreased; this is the principle of a surge tank, surge tank is usually cylindrical here, but in many design a surge tank with varying cross section.

Varying cross sectional area with high it is provided instead of a cylindrical one; because of it is flexibility in operation and because of it is fastness in operation. So, therefore, again and again I am telling you the providing a surge tank is very practical aspect, which see that the water NMR problem. When there is a sudden acceleration and deceleration for a long part of this pipe is reduced and at the same time the surge tank acts as a extra reservoir type of thing, which gives the extra water or takes up the extra water, when the load is altered. So, that is all.

Thank you.